DESIGN OF A CELLULAR REINFORCED CONCRETE DAM

BY

JULIAN FRANK

ARMOUR INSTITUTE OF TECHNOLOGY

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The Design of a Cellular Reinforced Concrete Dam for the Kensico Reservoir of the New York Catskill Mt. Water Supply

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Julian Frank

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I take this opportunity to thank Professors Phillips and Penn for their valuable suggestions given to me in the design of this Dam.

I References on Present Kensico Dam.

A. Catskill Water Supply of New York City,
By L. White.

B. Proceedings of New England Water Works
Association December 1915.

C. Engineering Record December 25, 1909.

D. Engineering News April 25, 1912.

II Brief History of Kensico Dam and Reservoir.

A. The Kensico Reservoir.

The Kensico Reservoir is an important feature of the Catskill Aqueduct project. It is located in the upper valley of the Bronx River in Westchester County, New York, about 3 mi. north of White Plains and forms a storage reservoir comparatively near the city for the Catskill water collected in the impounding reservoirs of which the Ashokan was the first to be constructed. It is the main distributing center for the 500 million gallon per day water supply for the city of New York.

About 15 miles beyond New York City's northerly boundary was Lake Kensico, a small reservoir developed about 30 years ago as a part of the water supply of the Borough of the Bronx. This reservoir lay in the bottom of a large basin which is the only available site near the city for a great storage and dis-

tribution reservoir along the Catskill aqueduct. Here a capacity of approximately 40 billion gallons is utilized by the construction of the Kensico Masonry Dam. Kensico reservoir is sufficient to supply the city for several weeks without receiving water from Catskill impounding reservoirs, thus permitting the portion of the aqueduct to the north, (between Ashokan and Kensico) to be cleaned or repaired. In the future it will also become the center from which other main delivery conduits will radiate into the metropolitan district. The storage behind the Kensico dam covers 2218 acres at elev. 355 above mean sea level, with a maximum depth of 155 ft. and an average depth of 53 ft.

The Catskill Aqueduct with a maximum daily capacity of 500 million gal. discharges into the upper end of Kensico Reservoir 4 mi. north of the dam over a weir 216 ft. long in the side of the aqueduct.

The hydraulic grade line of the aqueduct at this point is the same elevation as the normal surface of the full reservoir. The water after circulating through the reservoir is drawn through a short tunnel on the west side of the reservoir about a mile north of Kensico dam. Large gate chambers at both ends of this tunnel control the flow of water into the aqueduct. A reinforced concrete aqueduct connects the influent works with the upper effluent chamber so that the reservoir may be by-passed and water sent directly to the city if desirable. It is expected to maintain Kensico Reservoir full, drawing upon it only in emergency. The Kensico effluent works include an aeration basin, screen chamber and a reinforced concrete Venturi meter.

The by-pass aqueduct connecting the influent and effluent chambers is built along the west side of the reservoir and is a circular

reinforced concrete structure 11 feet in diameter. The reinforcing rods are 1 1/8 " square twisted steel bars arranged in double rings spaced 18" apart longitudinally. The construction of the reinforced aqueduct was required to be monolithic. It was built in sections about 45 feet long.

The upper effluent gate chamber through which the water is drawn from the Kensico Reservoir to the city is 52 feet square with the gate sills at Elevation 291.3. The water is controlled by a double set of four 5 feet by 8 feet sluice gates and the by-pass aqueduct connects with this gate chamber. After leaving this chamber the water passes through a tunnel 1600 ft. long to the lower gate chamber. This is 82 ft. by 100 ft. with floor level at Elev. 295.32. This chamber controls the water, delivering it directly to the aeration basin or to the turbine wells in

which power may be developed by using the available head when the aerator is not in use.

The Kensico aerator is a long concrete basin 460 ft. long and 240 ft. wide with six lines of reinforced concrete supply pipes discharging through 1750 nozzles arranged in rows and groups which with different sizes and shapes of jets make a wonderful fountain. The nozzles are designed with spiral veins, which cause the water to break into a fine spray aiding in the oxidizing effect of the air by exposing the drops for several seconds thus removing many of the causes of disagreeable tastes and odors. The aerator when operating absorbs about 25 ft. of available head. As the aerator passes the entire flow of the aqueduct it is believed to be the largest fountain in the world. The water after falling on the floor flows through a slot into a collective conduit beneath the floor, which conducts it back to the aqueduct.

B. The Present Kensico Dam.

Kensico Dam is 1830 ft. long on top and its maximum height is 307 ft. above the deepest part of the excavation. The top of the dam is 170 ft. above the old stream bed but only 130 ft. above the surface to which the earth is graded. It is 15 ft. above water level when the reservoir is just full. The dam's minimum thickness is about 28 ft. and its maximum thickness at the bottom about 230 ft. Of the masonry the great bulk is cycopean with concrete mixed approximately 1:3:6 using local sand and gneissoid granite. Owing to its very conspicuous location the dam received architectural treatment which while simple and dignified is commensurate with the magnitude and importance of the structure.

Lake Kensico had a maximum depth just back of the old dam of 45 ft., the new

dam will raise the water level 110 ft. or to elevation 355 above tide. The new reservoir will have a water surface of 3.75 sq.mi., and a very irregular shore line about 40 mi. long. New York City acquired 4481 acres altogether so that there is a park fringe of no mean proportions surrounding the new reservoir and a very large island within it. The flooding of the valley has necessitated the building of 8.5 mi. of first class highways and the construction of 3 reinforced concrete bridges. Two are girders, Bear Gutter bridge having three 38.5 ft. spans, and Cranberry Brook bridge with five exactly similar spans. Rye bridge has 5 segmental arches of about 135 ft. span.

C. The Geology of the Site.

At Kensico dam site the rock formations are quite similar to those at New Croton dam. The axis of the dam lies approximately east and west (S72° 02'E) with the downstream face southerly. On the easterly side of the valley a sound gneissoid granite merging into gneiss is found; on the westerly side the rock is a reasonably good schist; between these two lies a bed of Inwood limestone, some parts of which are almost a marble. Along the axis of the dam the limestone occupies a distance of 600 ft.

The side hills of the Bronx valley at the site of the dam rise about 180 ft. above the floor of the valley, the lowest point of which is at Elev. 300 above sea level. The east hill is of Fordham gneiss and the west hill of Manhattan schist with very light cover of soil. Between these

two formations is a stratum of Inwood limestone about 400 ft. thick. Geologically the valley is an eroded limb of a simple fold with a strike nearly north and south or at right angles to the line of the dam and an average dip to the west of 55°. The floor of the valley at the dam site is about 900 ft. wide with 10 - 30 ft. of modified drift overlying the bed rock. Some of the material is very fine, analyses showing that 96% will pass a #50 sieve. The core bearings of the preliminary survey revealed a pre-glacial gorge in the vicinity of the contact between gneiss and the limestone about 50 ft. wide at the top and about 120 ft. deep below the floor of the valley. At the depth of 30 ft. and again near the surface of the disintegrated rock at the bottom of the gorge layers of coarse sand and gravel were found.

III Proposed Reinforced Concrete Dam.

This Thesis consists of the design of a Dam which so differs from other Dams, that I have not been able to find anything in any engineering literature pertaining to one of such design. The one great advantage which this Dam has over hollow reinforced concrete dams is, in my mind, the narrowing of the width of the base of the dam, and the decrease of the angle of slope of the water face slab with the vertical. In a hollow reinforced concrete dam, Ambursen type, the upstream deck makes with the vertical an angle of 48 degrees, because it is practically the angle at which the friction produced by the weight of water on the deck of the Dam, plus the weight of the structure itself is approximately equal to the thrust of the water tending to push the dam downstream.

In my design by filling the cells with

sand allows the cutting in of the width of the base and yet keep the resultant pressure within the middle third. In connection with solid masonry dams, I believe that one of my type would be cheaper and one of much quicker construction, which is a vital thing in the construction of dams.

My design consists of a cellular reinforced concrete dam with the cells filled up with sand. I have chosen the Kensico Dam because it suits my purpose best. I have cut in on the width of the base of the original dam, making it 220 feet, and have made the slopes of the upstream and downstream decks of the same slope, namely 1 ft. vertical on .38 ft. horizontal. The top of the dam is 30 ft. wide on which is a 28 ft. roadway for highway traffic, The drainage of the roadway is provided for by making 8 in. pipe drains every 200 ft. of the dam, extending the pipes down through the dam

near the downstream slab and then out under the terrace and thence to the waste channel.

The buttresses are 20 ft. c. to c. and vary in thickness from 16 in. to 8½ ft. The upstream face slab varies from 8 in. to 9 ft.8 in., this being due to the water pressure. The inside sand pressure on the upstream slab is less than the water pressure, therefore, it does not affect its design. The back slab is of uniform thickness, 13 in. because by making horizontal intermediate slabs 15½ in. thick, every 20 ft. causes a constant head of sand on the face slabs. I have placed partitions or cell walls at such distances which do not make the cells too large. This can best be seen by referring to the drawing.

The main support of the Dam are the buttresses. The roadway slab rests on beams 3 ft. c. to c. which in turn rest on the buttresses. Due to the location of the dam it will receive

architectural treatment by facing the downstream slab with granite blocks.

Expansion joints are made every 60 ft. at one of the buttresses. The joint is simply a section of some special iron which resists corrosion. One-half of it is embedded in the concrete of one of the abutting sections. The concrete is allowed to harden with one edge of the metal projecting beyond it. The edge of the concrete and the projecting metal are heavily painted with asphalt, then the other, adjacent section of concrete is cast. When finished, the metal key is firmly gripped by one section and is free to slide in and out of the other. This is a simple and thoroughly satisfactory joint.

IV Design.

A. Allowed Stresses and Conditions of Design.

The dam was designed for the worst conditions, namely, 10 ft. of water over the waste weir which is in another part of the reservoir. This makes a total head for design of 245 ft. Roadway on dam was designed according to specifications, for uniform live load of 1440# per sq. ft.

Unit Stress in Concrete = 500#/sq.in.

" " " Steel = 16000#/sq.in.

$$p = \frac{8\ S_c}{42\ S_s} = \frac{8 \times 500}{42 \times 16000} = 0.0059.$$

$k = 0.3191.$

$j = 0.875.$

B. Roadway Slab and Beams.

I. Slab.

Floor slab of roadway to be supported on beams spaced 3 ft. c. to c. through the top width of dam.

Live Load --------------------	=	1440#/sq.ft.
Dead Load (Wearing Surface)--	=	50#/sq.ft.
Dead Load of Slab ------------	=	75#/sq.ft.
Total w	=	1565#/sq.ft.

$$M = \frac{wl^2}{10} = \frac{1565x3x3x12}{10} = 5634 \text{ in.\#}$$

$$d^2 = \frac{M}{p\ f_s\ j\ b} = \frac{5634}{.006x16000x7/8x12} = 5.6"$$

$d = 2.4"$

For Shear.

Shear = 40#/sq.in. with no shear reinforcing

$V = \frac{1}{2}$ span x w = 1.5x1565 = 2325#

$V = vjbd.$ Therefore $d = \frac{V}{vjb} = \frac{2325}{40x7/8x12} = 5.5"$

allow $1\frac{1}{4}"$ below steel.

Total depth of Slab to use = 7 in.

For Shear $A_s = p\ b\ d = .504$ sq.in./ft.

Use 2 -- 5/8" o rods/ft. of length of roadway.

For temperature stresses use ½% of gross area of concrete.

$A_s = .005 \times 12 \times 7 = .420$ sq.in.

Use for temperature 1 -- ¾" o rod/ft. of width of roadway.

II Beams.

Each Beam supports 3 ft. width of slab. Beams are supported every 20 ft., resting on top of the buttresses which are 20 ft. c. to c.

w (exclusive of wt. of beam) ---	=	1565#/sq.ft.
w (wt. of beam per ft.) --------	=	160# "
Total w --------	=	1725#/sq.ft.

Beam designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use $v = 120$#/sq.in.

$$b\ d = V/120 = \frac{1725 \times 10}{120} = 144 \text{ sq.in.}$$

Beams come out to be 10" x 16"

A_s = p b d = .006 x 10 x 16 = .960 sq.in.

Use 2 rows -- 5/8" o rods -- 5" c.-c.(rows 2" c.-c.)

u (bond stress) = V/*o j d = $\frac{17250}{4x1.96x7/8x16}$

u = 157#/sq.in.

Bond stress is high but will provide hooks.

Vertical Reinforcing.

i (diam. of rod) = 2.4 x u/f_s x d = .377"

Use 5/8" o rods.

Vert. Reinforcing extends beyond center of

support $x = \frac{L}{2} - \frac{v\ b\ j\ d}{w}$

$$x = \frac{20}{2} - \frac{40 \times 12 \times 7/8 \times 16}{1725} = 5.25 \text{ ft.}$$

Minimum Spacing at support.

$$S = \frac{3\ A_s\ f_s\ j\ d}{2\ V} = \frac{3 \times .442 \times 16000 \times 14}{2 \times 17250} = 7.5"$$

Note - * stands for Summation.

C. Intermediate Horizontal Slab.

All of these slabs have same thickness. Slabs supported every 20 ft. by the buttresses. They support 20 ft. of sand (weighs 100#/cu.ft.)

w (due to sand) = 20 x 100 = 2000#/ft.

w (dead wt.) $= \frac{16}{12} \times 144 = 195$#/ft.

Total w = 2195#/ft. of width.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

$t = V/bv = \frac{2195 \times 10}{12 \times 120} = 15.5''$ slab.

$A_s = p\ b\ d = .006 \times 12 \times 15.5 = 1.116$ sq.in.

Use 15/16" o rods 6" c. to c.

$u = V/{*}ojd = \frac{21950}{7.07 \times 7/8 \times 15\frac{1}{2}} = 219$#/sq.in.

Vert. reinforcing.

$i\ (\text{diam}) = 2.4 \times u/f \times d = \frac{2.4 \times 219 \times 15.5}{16000}$

i = .511"

Use 9/16" o rods.

Stirrups unnecessary at a distance from center of supports -

$$x = \frac{20}{2} - \frac{40 \times 7/8 \times 12 \times 15\frac{1}{2}}{2195} = 7.0 \text{ ft.}$$

Minimum spacing at supports,

$$S = \frac{3 \times 2 \times .2485 \times 16000 \times 7/8 \times 15.5}{2 \times 21950} = 7''$$

D. Back Slab Face.

Design of first 20 ft. of back slab for inside sand pressure.

Assume that buttresses take some of the bending but will be plenty strong enough.

Sand weighs 100#/cu.ft.

20 ft. of sand in upper bin.

There is a negative moment (M) at the corners due to sand pressure -

$$M = -1/12\ p\ (b^2 - b\ l + l^2)$$

where $b = 20$ ft. $l = 46$ ft.

The (+ M) at the middle of 20 ft. span of slab.

$$M = 1/24\ p\ (\ b^2 + 2\ b\ l - l^2\ )$$

Ref. Ketchen's - Walls, Bins & Grain Elevators.

$p = 100 \times 20 = 2000$#/sq.ft., unit pressure at bottom of slab at 20 ft. depth.

$$M = 1/24 \times 2000 \times 12\ (\ \overline{20}^2 + 2 \times 46 \times 20 - \overline{46}^2\ )$$

$M = 124000$ in.#

$M = p\ f_s\ j\ b\ d^2$ $d^2 = M/1008 = 122"$

$d = 11.0$ in.

The dead pressure of the slab increases the thickness by 2".

Wt. per ft. concrete $= 13 \times 144 / 12 = 156$#.

Total $p = 2156$#/ft.

$M = 1/24 \times 2156 \times 12 \; (20^2 + 2 \times 46 \times 20 - 46^2)$

$M = 134000$ in.#.

$$d^2 = \frac{M}{p \; f_s \; j \; b} = 133.0" \qquad d = 11.60 + 1.25 = 13"$$

$A_s = p \; b \; d = .006 \times 12 \times 13 = .830$ sq.in.

Use $\frac{3}{4}$" o rods 6" c. to c.

There being the same head of sand in each bin the pressure due to sand will be the same and the slab for sand will require the same thickness all the way down, therefore, make back slab 13" through height of dam.

The negative bending moment will be taken care of by tying in the cells with the reinforcing steel.

E. Front Water Face Slab.

First 20 ft. of slab.

At the bottom of the first 20 ft. there is 15 ft. head of water.

Water pressure on bottom = 62.5 x 15 = 940#/ft.

Assume a 10" slab. w = 10x144/12 = 120#/ft.
Total w = 1060#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 10600/1440 = 8" slab.

A_s = .006 x 12 x 8 = .576 sq.in.

Use 3 - 9/16" o rods / ft., 3" c. to c.

Vertical reinforcement only necessary (from support) $X = 10 - \frac{3360}{1120} = 7$ ft.

$$u = \frac{11200}{3x1.77x7/8x8} = 300\#/sq.in.$$

i = 2.4 x 300 x 8 / 16000 = .36" Use 3/8" o rods.

$$S \text{ (at end)} = \frac{3x2x.11x16000x7}{2 \times 11200} = 4"$$

Second 20 ft. of Slab.

Head of water at bottom of 40 ft. = 35 ft.

Water pressure = 62.5 x 35 = 2190#/ft.

Assume a 16.5" slab. w = 195#/ft.

Total w = 2385#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 23850/1440 = 16.5"slab.

A_s = .006 x 12 x 16.5 = 1.19 sq.in.

Use 4 - 5/8" o rods in two rows. At supports bend up the upper row.

$$u = \frac{23850}{4x1.96x7/8x16.5} = 211\#/sq.in.$$

i = 2.4 x 211 x 16.5 / 16000. Use 1/2" o rods.

$$X = 10 - \frac{40 \times 12 \times 7/8 \times 16.5}{2385} \doteq 7 \text{ ft.}$$

$$S \text{ (at end)} = \frac{3 \times 2 \times .307 \times 16000 \times 7/8 \times 16.5}{2 \times 23850}$$

S = 9 in.

Third 20 ft. of slab.

Head of water at bottom of 60 ft. = 55 ft.

Water pressure = 62.5 x 55 = 3440#/ft.

Assume 26" slab. w = 290#/ft.

Total w = 3730#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 37300/1440 = 26" slab.

A_s = .006 x 12 x 26 = 1.88 sq.in.

Use 4 - 13/16" o rods 6" c. to c. in two rows.

Upper two rows bent up at support.

$$u = \frac{37300}{4 \times 2.55 \times 7/8 \times 26} = 162\#/\text{sq.in.}$$

i = 2.4 x 162 x 26/16000 = .64 Use 5/8" o rods.

$$x = 10 - \frac{40 \times 12 \times 7/8 \times 26}{3730} = 7 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .307 \times 16000 \times 7/8 \times 26}{2 \times 37300} = 9"$$

Fourth 20 ft. of slab.

Head of water at bottom of 80 ft. = 75 ft.

Water pressure = 62.5 x 75 = 4680#/ft.

Assume 36" slab. w = 420#/ft.

Total w = 5100#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/ b v = 51000/1440 = 35.5"slab.

A_s = .006 x 12 x 35.5 = 2.66 sq.in.

Use 6 - 3/4" o rods space 6" c. to c.

Bend upper two rods up at support.

Run lower two rods through buttresses.

$$u = \frac{51000}{6 \times 2.36 \times 7/8 \times 35.5} = 112\#/\text{sq.in.}$$

i = 2.4 x 112 x 35.5/16000 = .62" Use 11/16" rods.

$$x = 10 - \frac{40 \times 12 \times 7/8 \times 35.5}{5100} = 6.5 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .371 \times 16000 \times 7/8 \times 35.5}{2 \times 51000} = 10 \text{ in.}$$

Fifth 20 ft. of slab.

Head of water at bottom of 100 ft.=95ft.

Water pressure = 62.5 x 75 = 5940#/ft.

Assume 45" slab. w = 530#/ft.

Total w = 6470#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/ b v = 64700/1440 = 45" slab.

A_s = .006 x 12 x 45 = 3.24 sq.in.

Use 6 - 7/8" o rods 6" c. to c.

Bend up top two at supports.

Run lower two rods through buttresses.

$$u = \frac{64700}{6 \times 2.75 \times 7/8 \times 45} = 101\#/\text{sq.in.}$$

i = 2.4 x 101 x 45/16000 = .675" Use 11/16" rods.

$$x = 10 - \frac{40 \times 12 \times 7/8 \times 45}{6470} = 7 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .371 \times 16000 \times 7/8 \times 45}{2 \times 64700} = 11''$$

Sixth 20 ft. of slab.

Head of water at bottom of 120 ft. = 115 ft.

Water pressure = 62.5 x 115 = 7200#/ft.

Assume 55" slab. $\qquad$ w = 660#/ft.

Total w = 7860#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 78600/1440 = 55" slab.

A_s = .006 x 12 x 55 = 3.96 sq.in./ ft.

Use 6 - 15/16" o rods 6" c. to c.

Bend up top two at supports.

Run lower two rods through buttresses.

$$u = \frac{78600}{6 \times 2.95 \times 7/8 \times 55} = 92.5\#/\text{sq.in.}$$

i = 2.4 x 92.5 x 55/16000 = .76" Use ¾" o rods.

$$X = 10 - \frac{40 \times 12 \times 7/8 \times 55}{7860} = 7 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 55}{2 \times 78600} = 17 \text{ in.}$$

Seventh 20 ft. of slab.

Head of water at bottom of 140 ft. = 135 ft.

Water pressure = 62.5 x 135 = 8450#/ft.

Assume 65" slab. w = 780#/ft.

Total w = 9230#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/ b v = 92300/1440 = 65" slab.

A_s = .006 x 12 x 65 = 4.68 sq.in.

Use 6 - 1" o rods. 6" c. to c.

Bend up top two at supports.

Run lower two rods through buttresses.

$$u = \frac{92300}{6 \times 3.142 \times 7/8 \times 65} = 87\#/\text{sq.in.}$$

i = 2.4 x 87 x 65 / 16000 = .85" Use 7/8" o rods.

$$X = 10 - \frac{40 \times 12 \times 7/8 \times 65}{9230} = 7 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 65}{2 \times 92300} = 18 \text{ in.}$$

Eighth 20 ft. of slab.

Head of water at bottom of 160 ft. = 155 ft.

Water pressure = 62.5 x 155 = 9680#/ft.

Assume 75" slab. $\quad w \quad = \underline{\ 900\#/ft.}$

Total $\quad w \quad$ = 10580#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/ b v = 105800/1440 = 74" slab.

A_s = .006 x 12 x 75 = 5.33 sq.in.

Use 8 - 15/16" o rods. 6" c. to c. in 4 rows.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{105800}{8 \times 2.95 \times 7/8 \times 74} = 69\#/\text{sq.in.}$$

i = 2.4 x 69 x 74/16000 = .77 in. Use 13/16" o rods.

$$X = 10 - \frac{40 \times 12 \times 7/8 \times 74}{10580} = 7 \text{ ft.}$$

$$S = \frac{3 \times 2 \times .518 \times 16000 \times 7/8 \times 74}{2 \times 105800} = 15 \text{ in.}$$

Ninth 20 ft. of slab.

Head of water at bottom of 180 ft. = 175 ft.

Water pressure = 62.5 x 175 = 10950#/ft.

Assume 85" slab. w = 1020#/ft.

Total w = 11970#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 119700/1440 = 84" slab.

A_s = .006 x 12 x 84 = 6.05 sq.in./ft.

Use 8 - 1" o rods 6" c. to c. in 4 rows.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{119700}{8 \times 3.142 \times 7/8 \times 84} = \cancel{XXXX}\ 65\#/\text{sq.in.}$$

i = 2.4 x 65 x 84 / 16000 = .82" Use 7/8" o rods.

X = 7 ft. out from support.

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 84}{2 \times 119700} = 17''$$

Tenth 20 ft. of slab.

Head of water at bottom of 200 ft. = 195 ft.

Water pressure = 62.5 x 195 = 12200#/ft.

Assume 94" slab. $\quad w = \underline{1130\#/ft.}$

Total $w = 13330\#/ft.$

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 133300/1440 = 93" slab.

A_s = .006 x 12 x 93 = 6.70 sq. in./ ft.

Use 9 - 1" o rods 8 of them 6" c. to c.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{133300}{9 \times 3.14 \times 7/8 \times 93} = 59\#/\text{sq.in.}$$

i = 2.4 x 59 x 93 / 16000 = .82" Use 7/8" o rods.

X = 7 ft. out from supports on each side.

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 93}{2 \times 133300} = 17''$$

Eleventh 20 ft. of slab.

Head of water at bottom of 220 ft.= 215 ft.

Water pressure = 62.5 x 215 =13450#/ft.

Assume 103" slab. w = 1240#/ft.

Total w =14690#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/ b v = 146900/1440 = 102" slab.

Use 8 - 1 1/8" o rods 6" c. to c. in 4 rows.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{146900}{8 \times 3.53 \times 7/8 \times 102} = 58\#/\text{sq.in.}$$

$i = 2.4 \times u \times d \; / \; f_s = .88$ in.

Use 7/8" o rods for stirrups.

X = 7 ft. on each side of support.

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 102}{2 \times 146900} = 17"$$

Twelfth **15** ft. of slab.

Head of water at bottom of 235 ft.=230 ft.

Water pressure = 62.5 x 230 = 14400#/ft.

Assume 112" slab. w = 1350#/ft.

Total w = 15750#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 157500 / 1440 = 110" slab.

A_s = .006 x 12 x 110 = 7.94 sq.in./ft.

Use 8 - 1¼" o rods 6" c. to c. in 4 rows.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{157500}{8 \times 3.93 \times 7/8 \times 110} = 52\#/\text{sq.in.}$$

i = 2.4 x 52 x 110 / 16000 = .86"

Use 7/8" o rods, for stirrups.

X = 7 ft. on each side of support.

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 110}{2 \times 157500} = 17"$$

Thirteenth 15 ft. of slab.

Head of water at bottom of 250 ft. = 245 ft.

Water pressure = 62.5 x 245 = 15300#/ft.

Assume 118" slab. w = 1420#/ft.

Total w = 16720#/ft.

Slab designed using no vertical reinforcing, the unit shear was found to exceed 40#/sq.in.

Use v = 120#/sq.in.

d = V/b v = 167200 / 1440 = 117" slab.

A_s = .006 x 12 x 117 = 8.43 sq.in./ft.

Use 8 - $1\frac{1}{4}$" o rods 6" c. to c. in 4 rows.

Bend up top two rows at supports.

Run lower row through buttresses.

$$u = \frac{167200}{8 \times 3.93 \times 7/8 \times 117} = 56\#/\text{sq.in.}$$

i = 2.4 x 56 x 117 / 16000 = .87"

Use 7/8" o rods for stirrups.

X = 7 ft. on each side of support.

$$S = \frac{3 \times 2 \times .601 \times 16000 \times 7/8 \times 117}{2 \times 167200} = 17"$$

F Cell Walls or Partitions.

Partitions to be placed as shown on the drawing.

Make walls nominal thickness of 12 in., because the head of sand on each side of them is the same.

The steel reinforcing is 3/4" o rods 12" c. to c., 2" from each face throughout the height of the wall.

The bringing of the steel of the partitions through the buttresses takes care of the negative bending moment at the corners of the cells, due to the sand pressure.

G Buttresses.

The first 40 ft., to the top of the second inside horizontal slab.

Load;

Roadway slab and beams = 1725#/ft. width.

1 panel of sand & slab = <u>2195 " "</u>
3920 " "

W/ft. length of dam = 3920 x 20= 78400#.

Assume 18" butt. 40 ft. length = <u>8640#</u>.

Total weight carried by 1st.40ft.= 87040#.

Compressive strength of concrete = 500#/sq.in.

Cross-section area of butt. = 87040/500 = 175 sq.in.

Thickness of slab = 175/12 = 15" Use <u>16</u>" slab.

Thickness at bottom of 40 ft. due to water pressure and upstream slab:

W = 2340 x 20 = 46800# Less than above.

For shear: t = 23400/1440 = 15½".

Make first 40 ft. of buttress 16" thick.

Front slab face steel to be brought through the buttress to the other end, thus tying the Cells in.

The second 40 ft., to the top of the fourth inside horizontal slab.

Load:

Roadway slab and beams = 1725#/ft. width.

3 panels of sand & slabs = 6585 " "

8310 " "

W/ft. length of dam = 8310 x 20 = 166200#.

Assume 32" butt. 40 ft. length = 15400#.

Total weight carried by 2nd.40ft. = 181600#.

Area of buttress = 181600 / 500 = 364 sq.in.

Thickness of slab = 364 / 12 = 32"

Thickness at bottom of 80 ft. due to water pressure and upstream slab:

W = 5100 x 20 = 102000# Less than above.

For shear: t = 51000 / 1440 = 33".

Make second 40 ft. of buttress 32" thick.

Refer to detail drawing for position and size, of reinforcing steel.

The third 40 ft. 120 ft. down.

Load:

Roadway slab and beams = 1725#/ft. width.

5 panels of sand & slabs = 10975 " "

12700 " "

W/ft. length of dam = 12700x20 = 254000#.

Assume 48" butt. 40 ft. length = 23000#.

Total weight carried by 3rd.40ft. = 277000#.

Thickness of slab = 277000 / 6000 = 48"

For water pressure thickness is O.K.

Make third 40 ft. of buttress 48" thick.

Refer to detail drawing.

The fourth 40 ft. 160 ft. down.

Load:

Roadway slab and beams = 1725#/ft.width.

7 panels of sand & slabs= <u>15065# " "</u>
16790# " "

W/ft. length of dam = 16790x20 = 335800#.

Assume 64" butt. 40 ft. length = <u>30800#</u>.

Total weight carried by 4th. = 366600#.

Thickness of slab = 366600 / 6000 = 64"

For water pressure thickness is O.K.

Make fourth 40 ft. of buttress 64" thick.

Refer to detail drawing.

The fifth 40 ft. 200 ft. down.

Load:

Roadway slab and beams = 1725#/ft.width.

9 panels of sand & slabs = 19800 " "

21525 " "

W/ft. length = 21525x20 = 430500#.

Assume 80" butt. of 40ft. = 38400#.

Total wt. carried by 5th. = 468900#.

Thickness of slab = 468900 / 6000 = 80"

For water pressure thickness is O.K.

Make fifth 40 ft. of buttress 80" thick.

Refer to detail drawing.

The last 50 ft. 250 ft. down.

Load:

Roadway slab and beams = 1725#/ft.width.

12 panels of sand & slab= 26400 " "

28125 " "

W/ft. length = 28125x20 = 562500#.

Assume 102"butt.of 50ft.= 48000#.

Total wt. carried by whole butt.= 610500#.

Thickness of slab = 610500 / 6000 = 102"

For water pressure thickness is O.K.

Make last 50 ft. of buttress 102" thick.

Refer to detail drawing.

Thickness of buttress varies from 16" at the top to 102" at the bottom.

H. Computation of the exact weight of dam
to find position of the Resultant Pressure.

The following is for 1 ft. width of dam.

Vertical section through sand bins.

First 20 ft:

Floor slab and beams	=	8350#
Water slab, 2/3x144x22.5	=	2160
Back slab, 13/12x144x22.5	=	3520
Sand, (28¼ + 44¼) 20/2x100	=	72500
Total wt. at 20 ft. down	=	86530#

Second 20 ft:

Weight of 1st. 20 ft.	=	86530#
Water slab, 16.5/12x144x22.5	=	4450
Back slab,	=	3520
1 hor. slab, 1¼x144x43.5	=	7610
1 vert. wall 18¾x144	=	2700
Sand, (43.5 + 58.5) 1875/2-2700	=	93625
Total wt. at 40 ft. depth	=	198435#

By the same method of computation as shown on the previous page, the weight of the dam at various distances down, was found to be as follows:

Total weight at 60 ft.	=	341185#
" " " 80 "	=	517505
" " " 100 "	=	724925
" " " 120 "	=	947175
" " " 140 "	=	1220595
" " " 160 "	=	1643515
" " " 180 "	=	1979535
" " " 200 "	=	2346955
" " " 220 "	=	2737375
" " " 250 "	=	3626200
Total weight of dam	=	3626200#
Vert. comp. of water pressure	=	983000
Total vert. weight	=	4609200#
Hor. comp. of water pressure	=	1870000#

By graphical methods the Resultant Pressure was found to fall well inside the middle third of the base of the dam.

DESIGN

OF A

LULAR REINFORCED CONCRETE DAM.

FOR THE

KENSICO RESERVOIR

OF THE

/ YORK CATSKILL WATER SUPPLY

A THESIS

PRESENTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN CIVIL ENGINEERING

SUBMITTED BY

Julian Frank

RMOUR INSTITUTE OF TECHNOLOGY

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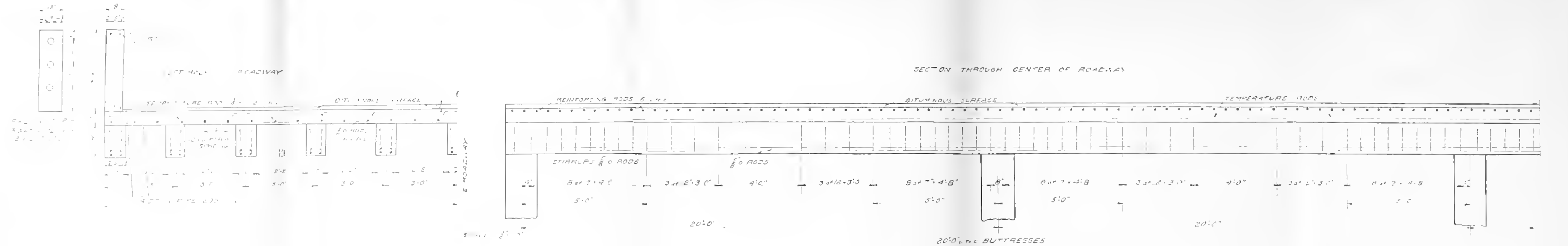
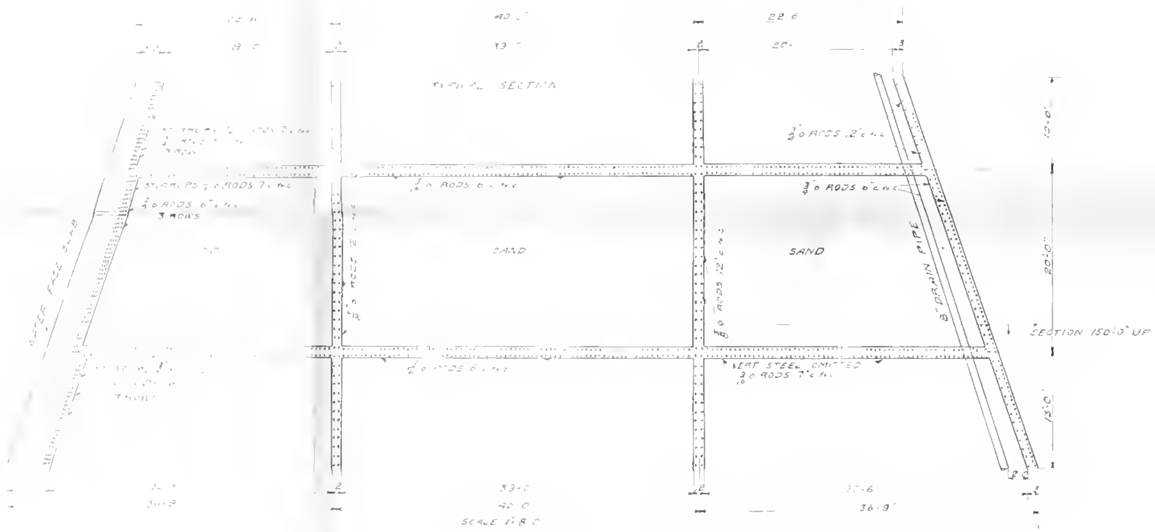
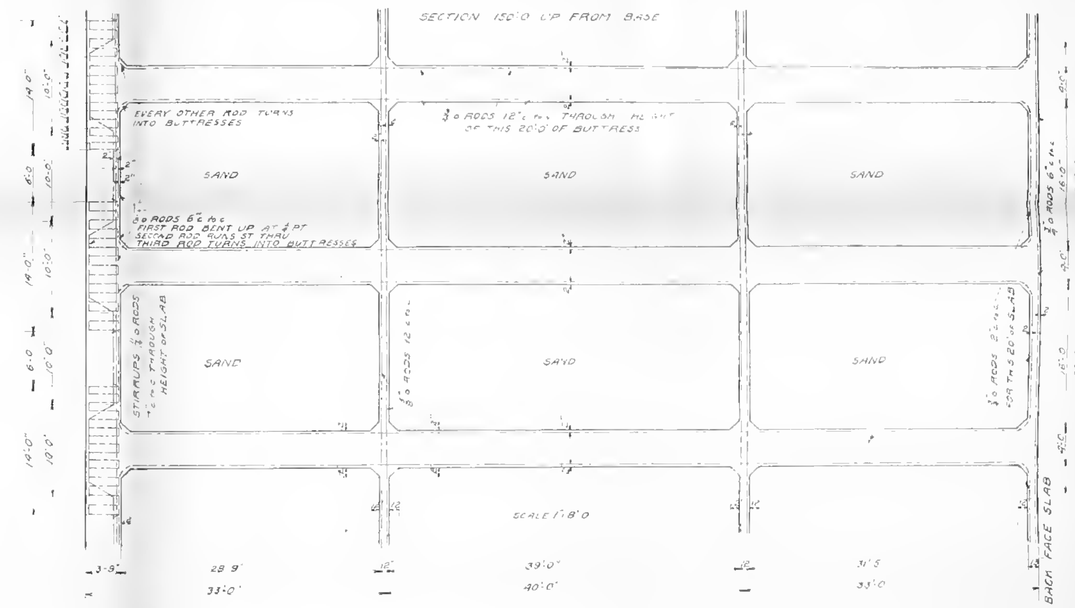
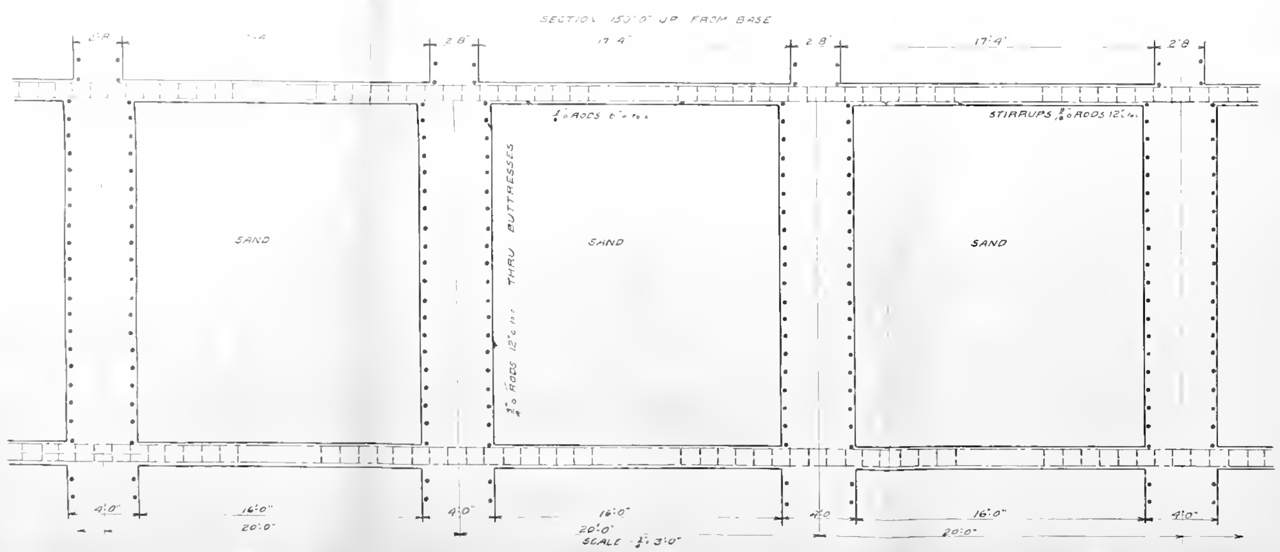
CIVIL ENGINEERING DEPARTMENT

MAY 1920









DETAILS
OF
NEW KENSICO DAM

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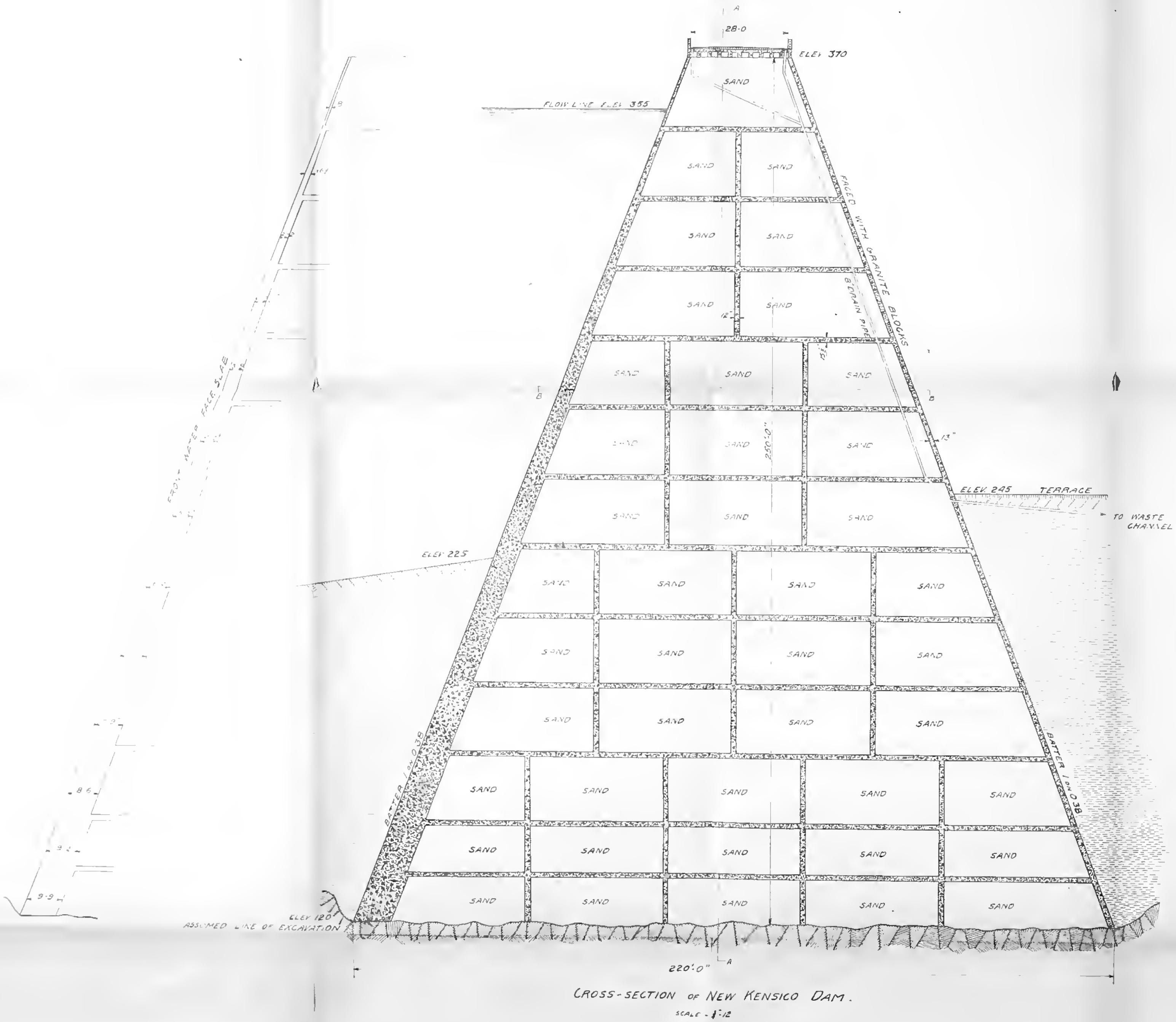
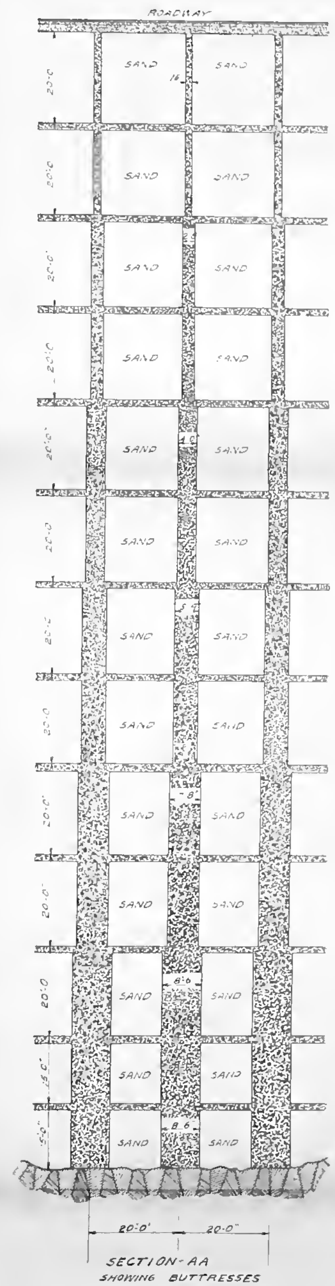
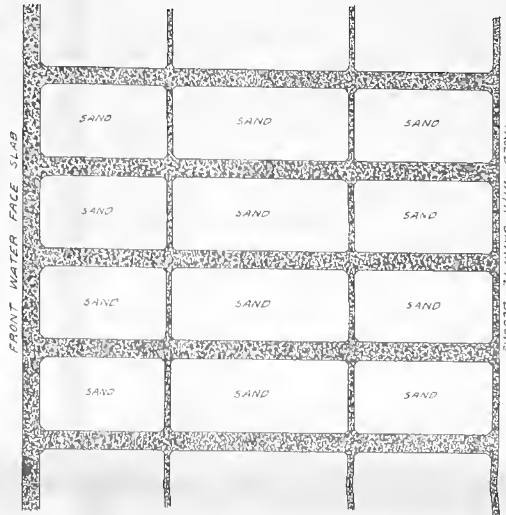


CROSS-SECTION OF NEW KENSICO DAM.

SCALE - ⅛" = 1'



SECTION-AA
SHOWING BUTTRESSES



SECTION-BB

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